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Stephan H. Hussman et al.

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For: METHODS AND APPARATUS FOR CONTROL OF INDUCTIVELY COUPLED POWER TRANSFER SYSTEMS

Examiner: Not Yet Assigned

AFFIRMATION OF PRIORITY CLAIM

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

Applicant hereby claims priority under 35 U.S.C. 119 based on the following prior foreign applications filed in the following foreign countries on the dates indicated:

Country	Application No.	Date
New Zealand	526115	May 23, 2003
New Zealand	529869	November 27, 2003

Certified copies of the aforesaid Patent Applications were received by the International Bureau on June 14, 2004 during the pendency of International Application No. PCT/NZ04/000096. A copy of Form PCT/IB/304 is enclosed.

Dated: November 23, 2005

Respectfully submitted,

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PCT/NZ2004/000096

PRIORITY DOCUMENT
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REC'D 17 JUN 2004
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CERTIFICATE

This certificate is issued in support of an application for Patent registration in a country outside New Zealand pursuant to the Patents Act 1953 and the Regulations thereunder.

I hereby certify that annexed is a true copy of the Provisional Specification as filed on 23 May 2003 with an application for Letters Patent number 526115 made by Auckland UniServices Limited.

Dated 9 June 2004.

Neville Harris

Neville Harris
Commissioner of Patents, Trade Marks and Designs

COMMISSIONER OF PATENTS, TRADEMARKS & DESIGNS
NEW ZEALAND

526115

Patents Form No. 4

Our Ref: WEJ504325

Patents Act 1953

PROVISIONAL SPECIFICATION

METHODS AND APPARATUS FOR DETUNING A PICK-UP OF A CONTACTLESS POWER SUPPLY

We, **AUCKLAND UNISERVICES LIMITED,** a New Zealand company, of Level 10, 70 Symonds Street, Auckland, New Zealand do hereby declare this invention to be described in the following statement:

PT043670095

Intellectual Property Office of NZ

23 MAY 2003

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METHODS AND APPARATUS FOR DETUNING A PICK-UP OF A CONTACTLESS POWER SUPPLY

FIELD OF THE INVENTION

This invention relates to Inductively Coupled Power Transfer (ICPT) power supplies and pick-ups for such power supplies.

BACKGROUND

ICPT power supplies (also known as contactless power supplies) are known to have significant advantages in applications such as the materials handling, lighting and transportation industries. These power supplies have traditionally been used with high power supplies at a level of several or tens of kilowatts. However, there are many applications in both high and low power systems in which use of these power supplies is advantageous.

OBJECT

It is an object of the present invention to provide a method of controlling, or apparatus for, an ICPT power supply which will at least provide the public with a useful alternative.

SUMMARY OF THE INVENTION

Accordingly in one aspect the invention may broadly be said to consist in an ICPT power supply pick-up having a tuned pick-up circuit and detuning means operable to selectively detune the pick-up circuit.

Preferably the detuning means includes a detuning inductor.

Preferably the detuning inductor comprises an inductance and a switching means.

Preferably the apparatus includes control means to control the switching means so that the inductance selectively draws current from the pick-up circuit to thereby detune the pick-up circuit.

Preferably operation of the detuning means controls the power transferred to the pick-up.

Preferably the pick-up power supply output is connected to a sensor or other load(s) which is energised by the pick-up power supply.

In a further aspect, the invention may broadly be said to consist in an ICPT power supply having an electric power supply, a primary conductive path connected to the electric power supply, and one or more pick-ups according to the preceding statement of invention.

In a further aspect the invention may broadly be said to consist in a method for controlling power drawn by a pick-up of an ICPT power supply, the method including the steps of sensing a load condition of the pick-up, and selectively detuning the pick-up circuit depending upon the sensed load condition.

Preferably the method includes the step of detuning the pickup circuit moves the resonant frequency of the pick-up circuit away from a tuned condition.

Preferably the step of detuning the pick-up circuit includes the step of controlling a detuning inductor.

Preferably the step of controlling a detuning inductor includes the step of switching the inductor into the pick-up circuit to detune the pick-up circuit and switching the detuning inductor out of the pick-up circuit to tune the pick-up circuit.

In a further aspect the invention may broadly be said to consist in a control system having a controller, at least one sensor for providing information to the controller, the at least one sensor having drive means and being mounted on a track so as to be moveable along the track by the drive means, the track including a primary conductive path which can be energised by an alternating current power supply, the sensor having an inductive pick-up which receives electric energy from the primary conductive path without being electrically connected to the primary conductive path, and the pick-up providing a power supply required for operation of the sensor.

The invention may also broadly be said to consist in any new part feature or element disclosed herein, or any new combination of such parts, features or elements.

For the purposes of this specification, the word "comprise" and variations such as "comprises" or "comprising" is to be interpreted in an inclusive sense unless the context clearly dictates the contrary.

DRAWING DESCRIPTION

One or more examples of an embodiment of the invention will be described below with reference to the accompanying drawing in which:

Figure 1	is a diagram of the basic structure of an ICPT power supply,
Figure 2	is a diagram of a known pick-up circuit topology for an ICPT power supply,
Figure 3	is one example of a pick-up circuit topology according to the present invention,
Figures 4 & 5	are graphs of output and gate voltage waveforms for the pick-up topology of Figure 2, and
Figure 6	is a graph of output and gate voltage waveforms for the pick-up topology of Figure 3.

DETAILED DESCRIPTION

Referring to Figure 1, the basic structure of an ICPT power supply (also known as a contactless power supply) system is shown. The system generally comprises two electrically isolated parts. The first part consists of a power supply such as a resonant converter (2) which has inputs (4) for connection to a source of electrical energy, in this example the inputs (4) may be connected to a 50 Hertz mains supply. The first part also includes a primary conductive path (6) which is supplied with alternating current from the resonant converter (2). The primary conductive path (6) is usually in the form of an elongated "track" along which one or more of the second parts is located. In this example, the main function of the converter is to supply a nominally constant high frequency AC current of about 20 amps rms at 40 kHz with a sinusoidal waveform in the track loop.

The second part consists of one or more pick-ups (8), each of which includes a pick-up coil (10). The pick-up also includes a controller (12) to control the transfer of power from the track loop to the pick-up. The power is supplied to a load (14). In this example the controller (12) comprises a microcomputer to control the pick-up circuit in accordance with

the invention, as will be described further below. Also, in this example, the load (14) comprises a sensor such as a fast moving sensor. One example of such a sensor is a camera which may be required to travel the length of the track loop (6) rapidly in order to provide information for implementation of a control system or process in an industrial environment.

Due to the mutual magnetic coupling between the primary conductive path (6) and the secondary pick-up coil (10), an electromotive force is induced in the pick-up coil (10). This voltage then becomes the source for the secondary power supply. Since then magnetic coupling is very loose compared to normal closely coupled transformers, the induced voltage is usually unsuitable for direct use. As such, a control mechanism is necessary to regulate the power in the form required by the load (14). In the fast moving sensor example discussed with reference to Figure 1, the output of the pick-up required by the sensor is normally 24 volts DC.

Turning now to Figure 2, a known pick-up circuit topology is shown. The operation of this circuit topology is described in US patent no. 5,293,308. In Figure 2, voltage source (20) represents the voltage induced in the pick-up coil (10). A parallel tuning capacitor (22) is provided to boost the induced voltage which is usually very low. Rather than being parallel tuned, the pick-up may be tuned by a series capacitor (not shown). The tuned voltage is rectified to DC by a full wave rectifier (24), although half wave rectification could also be used. An inductor (26) protects semi-conductor switch (29) which includes an anti-parallel diode (30). An output diode (32) prevents discharge of a filter capacitor (34) when switch S is closed. The filter capacitor (34) has the load (36) connected in parallel with it.

As described in US patent 5,293,308, operation of switch (28), so that the switch is in the closed state can effectively decouple the pick-up coil (10) from the primary conductive path (6). In this way, the power flow from the primary conductive path (6) to the pick-up can be controlled by controlling switch (28).

There are two main ways of controlling switch (28). The first is a simple hysteresis control method which is normally used for low switching frequency operation. In this method a band is set up within a small percentage of a given output reference voltage, for example 24 volts DC for the moving sensing example. If the output voltage is higher than the upper triggering point, the switch is turned on to stop the charging of the output capacitor

(34). When the voltage is lower than the triggering point, the switch is turned off enabling the current to flow so that output capacitor (34) is charged. Therefore, the actual switching frequency is primarily determined by the width of the error band, the load and the properties of the filter capacitor (34).

Constant frequency PWM (Pulse Width Modulation) control is normally used for high frequency switching operation of switch (28). The controllers that may be used for this methodology include analogue PI (Proportional-Integral) controllers or micro computer based digital controllers. With the PWM controlled high frequency switching scheme, the switch is controlled on and off at a constant frequency, but the duty cycle is changed dependant upon the load (36). Therefore at high loads, the switch has a relatively long off time compared to the on time of the switch. At light loads, the duty cycle approaches one, meaning that the average on time is very long compared with the off time of the switch.

An important concern with the low frequency switching technique is the high power loss problems at no load or lightly loaded conditions. Under ideal no load conditions, the capacitor (34) will maintain the output voltage constant so there is no need for any charging current. Therefore, the switch (28) is always on, resulting in large conduction losses. In a practical circuit, although the switch needs to be turned off occasionally to let the current charge the capacitor for practical power loss compensation, the switch is on most of the time. Therefore the maximum short circuit current almost always flows in the circuit.

In the PWM high speed switching approach, because the shorting switch (28) is hard-switched, the switching losses become considerably high at high-frequencies. Also, at no load or lightly loaded conditions, the long on time of the switch results in high conduction losses in addition to the high frequency switching losses.

Since all the power flow with this known circuit is controlled by the shorting switch (28), the stress and power losses of the switch are high.

We have proposed an alternative method for power control by using a variable inductor or capacitor to detune the tuned pick-up circuit dependent on load conditions.

An example of a pick-up topology which includes a variable inductor is shown in Figure 3.

The topology in Figure 3 is a parallel tuned pick-up i.e. the tuning capacitor (22) is connected in parallel with the pick-up coil (10). The detuning inductor (40) is also connected in parallel with the pick-up coil and the tuning capacitor. However, a detuning capacitor may be used instead to replace the inductor (40). Furthermore, the tuning capacitor (22) could, by the use of an appropriate switch or switches be effectively transformed into a detuning capacitance. Also, the pick-up coil could be used in accordance with the invention to provide the variable inductance.

Turning to Figure 3, the detuning element comprises an inductance (40) with two switches (42) and (44) with appropriate drivers (not shown) to control the voltage or current flowing through the reactive component.

We have found that we can use fast semiconductor switches such as MOSFETs and IGBTs to control an inductor in such a manner that a variable inductance is provided in the pick-up circuit. Fast switches are necessary with the high frequencies (10 – 100 KHZ) used in ICPT power systems. However these switches are DC switches having only unidirectional current flow control. To accommodate alternating currents, two such DC switches may be used represented by switches (42) and (44) in Figure 3.

Each of the switches (42) and (44) has associated antiparallel diodes (46) and (48) respectively, which allow the alternating inductor current to flow in both directions. Thus the inductor (40) can be controlled "on" to detune the circuit when there is no load or when the load is very light. Under normal loading conditions the inductor can be switched "off" so that the pick-up circuit is tuned back again to transfer the required power.

The switches (42) and (44) are controlled dependant on the current in the pick-up resonant circuit such that the inductor (40) is phase controlled. The switches (42) and (44) are initially controlled by both being turned on. This allows the inductor current to increase gradually in one direction, depending on the direction of the applied voltage. Therefore, zero current switching (ZCS) turning on is essentially achieved. In order to achieve zero current switching when turning off, the inductor current is detected by detection means (not shown) and a switch is only turned "off" when its anti-parallel diode is conducting. In this way, each switch (42) or (44) is not only switched at zero current but also at approximately zero voltage conditions (only the diode voltage drop of about one volt). Therefore the switching losses are significantly reduced.

Also, because only a small portion of the short circuit current is required to detune the circuit, the conduction losses introduced in the phase controlled inductor are negligible.

Figures 4, 5 and 6 illustrate simulations of circuit topologies discussed above using PSPICE simulation software. In Figure 4, the output (i.e. voltage across the filter capacitor (34), and the gate voltage (i.e. the gate drive voltage applied to switch 28) are shown for the circuit topology of Figure 2 under normal loading conditions e.g. 20 watts.

Turning to Figure 5, the same waveforms are shown when the load is reduced to a light load condition e.g. one watt. As can be seen, when the load is reduced to this lower level, then the shorting switch is in the "on" state most of the time as shown in Figure 5. The sustained short circuit condition of the switch (28) causes large power losses.

In Figure 6 waveforms for the same parameters as described with reference to Figures (4) and (5) are shown. However, in this instance the circuit topology is that of Figure 3 under a light load condition, such as one watt. Therefore in figure 10, the detuning inductor is switched on to be connected across the parallel tuning capacitor as shown in Figure 3. The circuit is detuned so that the off time span is much longer compared to the previous tuning condition shown in Figure 5. This can clearly be seen from the results shown in Figure 6. The reason for a long off time is that the output charging current is much smaller under a circuit detuning condition. Obviously, a shorter time helps to reduce the power losses at the shorting switch and reduce its heat sink requirements. The simulation results have shown that the reactance of the phase controlled inductor can be at least five times larger than that of the power pick-up (Figure 6 shows the situation of seven times). Therefore, the current flowing through the phase controlled inductor is at least five times smaller so the conduction power losses are very small.

Those skilled in the art will appreciate that although the example illustrated in Figure 3 refers to switching the detuning inductor (40) into the circuit or out of the circuit, and controlling the output voltage using the switch (28), it will be seen that the detuning inductor, or another variable reactance may be used to completely control the output voltage or current. Therefore, in the case of a variable reactance such as inductor (40) and switches (42) and (44), the switches (42) and (44) may be controlled to control the current through the inductor (40) in order to selectively tune the pick-up and therefore provide a controlled output voltage or current across the filter capacitor (34) without using the shorting switch S (figure 3) and the back flow blocking diode D (figure 3).

There are a wide variety of applications for the invention including delivery of electrical energy to a variety of loads, including sensors, in environments where traditional conductive paths are undesirable. Examples include production facilities in clean room environments; moving apparatus such as fast-moving sensors, or forestry, underwater and mining environments where traditional conductive elements experience excessive wear; and marine environments for which the invention can allow sensors or other electrical loads on a marine vessel, for example, to be reliably supplied with electrical energy despite the adverse environment. The invention provides a control mechanism for ICPT systems which has significant efficiency benefits. A control system which uses an ICPT system for providing a power supply to moving sensors or other loads is also provided.

PSPEC32610

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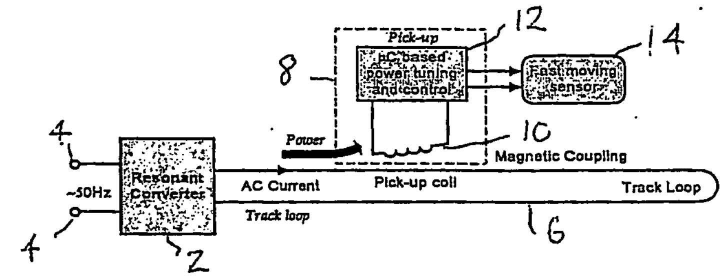

FIG 1

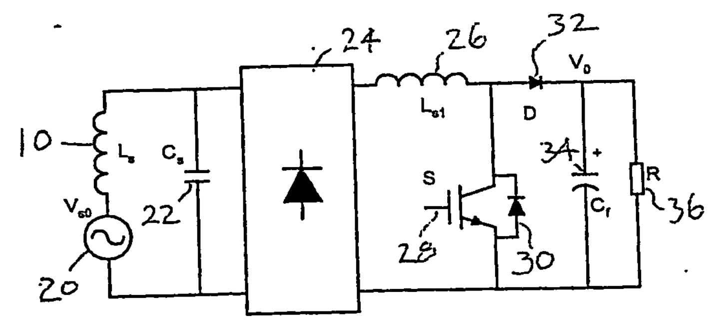

FIG 2

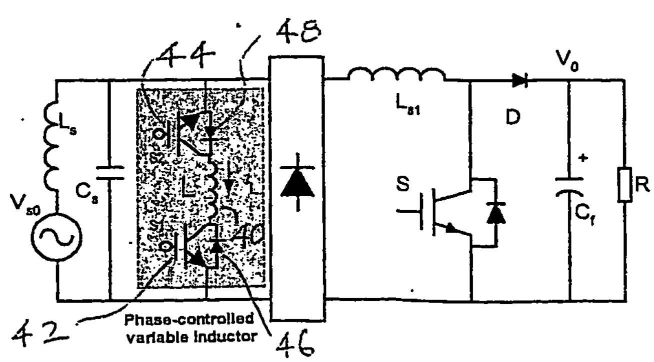

FIG 3

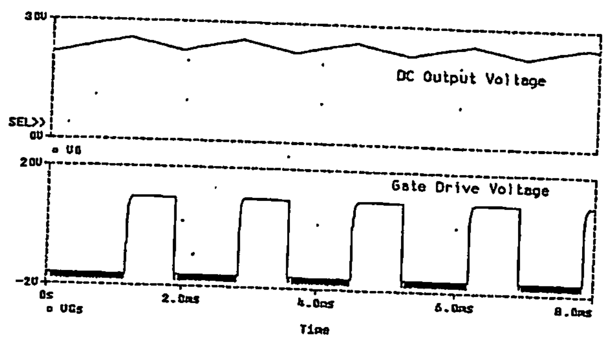

FIG 4

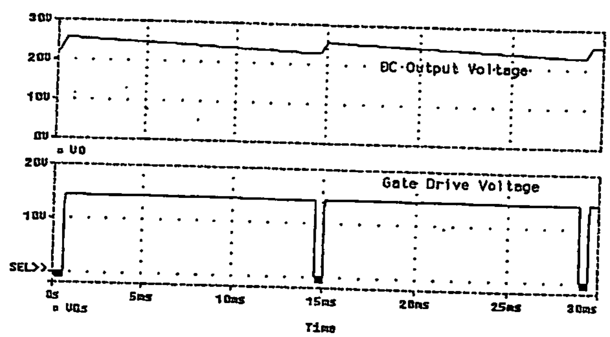

FIG 5

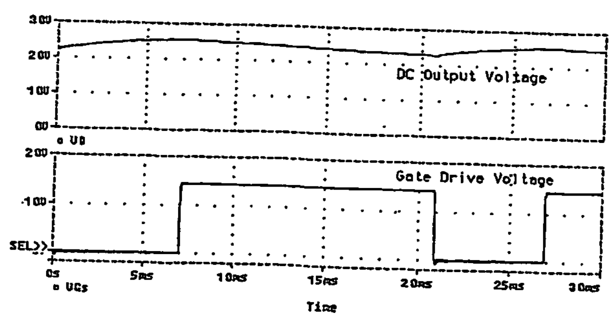

FIG 6